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OXYGEN INJECTION IN FOUNDRY STEELMAKING PRACTICE

by

K. Knaggs

This article is reprinted from the Journal of the British Steel Castings Research Association. The author is a senior investigator on the staff of the British Steel Castings Reseearch Association.

Data collected from 50 production heats in member foundries showed wide variations in the efficiency of oxygen consumption. This report discusses factors which influence the efficiency of oxygen usage and indicates the type of simple control chart which it may ultimately be possible to produce with a view to improving the efficiency of oxygen injection. Work along these lines is now continuing under carefully controlled conditions in the resistor rod furnace at the B.S.C.R.A. laboratories, it having already been established that results obtained in this furnace are comparable with industrial practice in arc furnaces.

Introduction

Since 1952 a survey has been made of oxygen injection practice in ten steel foundries. One result of this survey was to indicate a wide variation in the efficiency of oxygen utilization.

As far as possible, data were obtained on the following items in each heat surveyed: (1) weight of metal in bath; (2) temperature of metal before and after injection; (3) analysis of slag before and after injection; (4) analysis of metal before and after injection; (5) volume of oxygen injected (at N.T.P.); (6) rate of oxygen injection, and (7) duration of injection period.

The procedure was repeated for a number of heats made in each furnace. All the furnaces concerned were basic lined. No attempt was made to alter the prevailing practice in any particular melting shop so that the survey was based, as far as possible, on the regular practice at each foundry. These data have been analysed with a view to determining the reasons for the wide range of oxygen usage. A first attempt, made along the conventional lines of studying slag/metal reactions and equilibria, proved to be negative, and it was concluded that the oxidizing power of the slag has little effect on metalloid removal during the period of oxygen injection compared with the oxidizing power of the gaseous oxygen being blown. In this report, therefore, effort has been concentrated on a study of the oxidation reactions taking place in the metal bath and the factors affecting these reactions, special attention being paid to the efficiency of carbon removal.

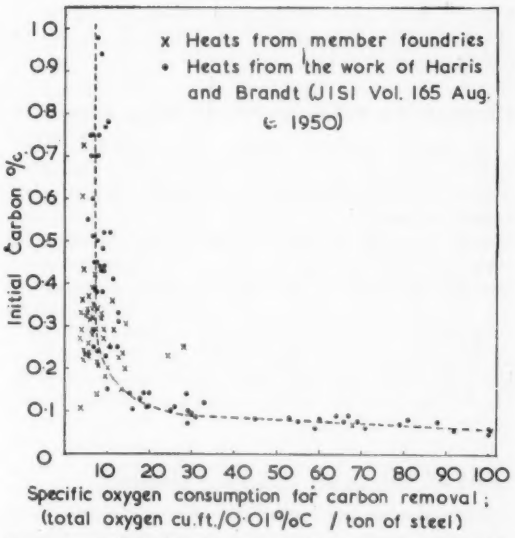

Figure 1—Relationship between specific oxygen consumption and initial carbon content.

Relating Oxygen Usage to Carbon Removal

The criterion generally used when studying carbon removal is known as the "specific oxygen consumption" (S.O.C.c) which is given by:

$$\text{S.O.C.c} = \frac{\text{vol. oxygen blown, cu. ft.}}{\text{points (0.01\%) carbon removed} \times \text{wt. of bath, tons}}$$

By plotting the initial carbon contents against S.O.C.c, the relationship shown in Figure 1 was obtained. This relationship substantiates the previous work of Harris and Brandt[1] whose data are also shown in the diagram. It must be noted that the marked relationship shown in Figure 1 makes no allowance for the size of furnace, the temperature before blow, the presence of the other dissolved elements or the rate of blowing, and thus indicates that the major consideration in carbon removal is the initial carbon content. Using the criterion thus set up, the effects of the other variables can now be considered.

Effect of Temperature on Carbon Removal

It is known from thermodynamic principles and from practical experience that as the temperature of the metal bath rises, the removal of carbon by oxygen becomes easier. Thus, as the bath temperature prior to the oxygen blow is increased, the corresponding S.O.C.c figure, for a given initial carbon level, should be reduced. This statement is substantiated to some extent by the limited temperature data available, since temperatures around 2910 degrees F lie to the left of the curve in Figure 1, and temperatures around 2730 degrees F lie to the right.

Effect of The Value of The Finishing Carbon

In most of the heats studied, the practice has been to blow down to a carbon level of not less than 0.08 percent. In such cases the overall efficiency of carbon removal is quite good. In a few cases and also in the heats reported by Harris and Brandt, the carbon was blown down within the region of 0.04 to 0.06 percent C. This has the effect of reducing the efficiency of carbon removal, for it can be seen from Figure 1 that the results of Harris and Brandt lie to the right of the results from member foundries, in spite of the fact that the initial carbon levels in Harris and Brandt's results are, on the whole, much higher than the others.

Effect of The Other Dissolved Elements

The only true method of considering the efficiency of oxygen usage is to take into account all of the dissolved elements in the bath. In the steels studied in this survey, however, the concentration of elements other than carbon and manganese was usually low. Furthermore, since the oxygen requirement for manganese oxidation is low relative to that required for carbon oxidation, on a weight for weight basis, the effect of other dissolved elements on the efficiency of carbon removal is not marked.

Effect of The Rate of Oxygen Blowing

It would be expected that for a given bath size, there would be a blowing rate which would give maximum efficiency at a given temperature, since below this given rate, the bath would be insufficiently agitated and above this rate, the time of contact between oxygen and metal would be too short.

Charles[2] quotes the following data for almost identical heats in a 3-ton capacity furnace.

Specific Oxygen Input *cu.ft/min/ton*	S.O.C. *cu.ft/ptC/ton*
55	5.60
83	5.05
100	8.10
217	17.35

In the data collected from members, there are not enough heats which are sufficiently identical for any valid conclusions on the effect of the rate of blowing oxygen to be drawn.

The Effect of Furnace Size

Provided that the terms specified oxygen consumption and specific oxygen input are used in considering the efficiency of carbon removal and the rate of blowing oxygen, and that the volume of oxygen blown is considered as a volume relative to the weight of metal, that is cubic feet per ton, then there does not seem to be any major effect of furnace size on the efficiency of oxygen blowing.

The Oxidation of Manganese

It is possible to consider the criterion for the efficiency of removal of manganese similarly to that of carbon. That is:

$$\text{S.O.C.Mn} = \frac{\text{vol. oxygen blown, cu. ft.}}{\text{points (0.01\%) Mn removed} \times \text{wt. of bath, tons}}$$

A tentative relationship (Figure 2) can then be obtained by plotting the values of S.O.C.Mn against the respective initial manganese concentrations. In studying the efficiency of manganese oxidation, the following factors appear to be effective:

1. The initial concentration of manganese.
2. The initial concentration of the other dissolved elements.
3. The temperature of the bath when blowing commences, since it is known that manganese is oxidized more readily as the temperature is lowered.

From Figure 2 it can be seen that down to an initial manganese concentration of approximately 0.6 percent, the overriding factor governing the removal of manganese is its initial concentration.

It is most likely that a major factor affecting the efficiency of manganese removal is the initial carbon concentration since any oxygen used for oxidation of carbon will not be available for oxidation of manganese. This factor assumes further importance when it is remembered that the oxygen required to remove one pound of carbon is nearly 15 cubic feet and that required to remove one pound of manganese is less than 4 cubic feet (assuming 100 percent efficiency of oxidation). It can be justly claimed, therefore, that below 0.6 percent Mn, the effect of carbon being oxidized in preference to, or at the same time as, manganese, is the main cause of the variable efficiency of manganese oxidation.

The temperature factor plays a less dominant role. It can be said, however, that heats with S.O.C.Mn values to the left of the dotted line in Figure 2 were mainly blown at temperatures below 2800 degrees F, and that heats blown at temperatures above 2800 degrees F tend to have S.O.C.Mn values which lie to the right of this line.

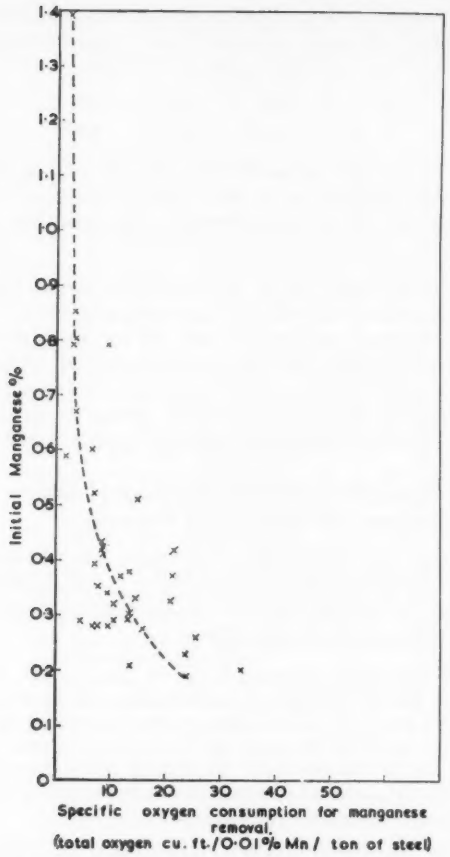

Figure 2—Relationship between specific oxygen consumption and initial manganese content.

The Oxidation of Silicon

In the steelmaking practice considered here, the silicon concentration before oxygen blowing is nearly always below 0.1 percent. It is sufficient to mention that where the silicon is above 0.1 percent before the oxygen blow, it falls to below this value during blowing, and where the silicon is below 0.1 percent before the oxygen blow, there is sometimes a slight reversion of silicon to the metal and sometimes a slight oxidation of silicon out of the metal.

Factors Affecting the Overall Efficiency of Oxygen Usage

When considering the efficiency of the oxygen blowing operation, it is necessary to decide whether it is the efficiency of removal of any specific element that is under consideration or whether the efficiency required is the overall efficiency of oxygen used in removing the various amounts of all the elements dissolved in the bath. If the former is the one desired, then the S.O.C. figure for that element, as previously calculated in this paper for manganese and carbon removal, gives a very sound indication of the relative efficiency of various heats and need not be rediscussed here, except to point out that if oxygen was used completely for the oxidation of carbon and was used 100 percent efficiently, then the $S.O.C._C$ figure would be 3.34 cu.ft/0.01 percent C/ton. The corresponding figure for manganese removal is 0.73 cu.ft/0.01 percent Mn/ton.

The efficiency to be considered in the remainder of this section is the overall efficiency of oxygen usage, by which is meant the oxygen used by stoichiometric requirement (i.e., calculated from the weight of the elements removed) divided by the actual volume of oxygen blown.

The volume of oxygen per ton of steel which can be efficiently used for metalloid oxidation when blown into a bath of steel depends on two factors: (1) the tendency of the various oxidation reactions to take place at the particular bath temperature; (2) the molecular concentrations of the dissolved elements taking part in the oxidation reactions.

Due to insufficient temperature data, a mean temperature of 2870 degrees F was assumed. A measure of the "oxidation capacity" of the bath at this temperature was derived by obtaining a value for each element representative of the product of the factors mentioned above for each metalloid and adding together the values so obtained for all the metalloids dissolved in the bath. The measure of the capacity of the melt to use oxygen efficiently, obtained in this way, was called the "cumulative potential".

The factor expressing the relative tendency of the reactions to proceed was derived from the free energy changes of the following reactions at an average temperature of 2870 degrees F.

(1) $C+O=CO(g)$ $\quad \Delta F_1^\circ = -22{,}900$ cal.

(2) $Mn+O=MnO$ $\quad \Delta F_2^\circ = -13{,}000$ cal.

(3) $1/2\ Si+O=1/2\ SiO_2$ $\quad \Delta F_3^\circ = -19{,}400$ cal.

(4) $2/3\ Cr+O=1/3\ Cr_2O_3$ $\quad \Delta F_4^\circ = -10{,}600$ cal.

Using a relative factor of 1.0 for manganese as an arbitrary reference value, the relative factors for carbon, silicon and chromium are determined by dividing ΔF_1°, ΔF_3° and ΔF_4° by ΔF_2°. The factors (R_1) thus obtained are shown in Table I.

A relative measure of the number of moles of each element in the bath was derived as follows. The factor for manganese is again assigned the arbitrary

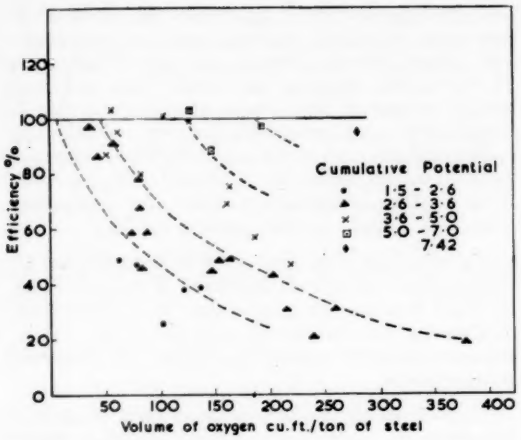

Figure 3—Efficiency of oxygen usage versus volume of oxygen blown per ton of steel.

value of 1.0. The factors for carbon, silicon and chromium (R_2) are then obtained by dividing the molecular weight of manganese by the fraction of the molecular weight of the element under consideration as given by the corresponding oxidation reaction.

For example

$$R_2 \text{ (chromium)} = \frac{55}{\frac{52 \times 2}{3}} = 1.59$$

See Table I for factors (R_2) derived by this method.

Finally, a total factor for each element (R_t) is found by multiplying R_1 and R_2. The total factors are also tabulated in Table I. The cumulative potential may now be calculated. It is the sum of the total relative factors multiplied by the weight percent of the corresponding element in the bath.

$$\text{C. P.} = (R_t)_C \times \text{Wt\% C} + (R_t)_{Mn} \times \text{Wt\% Mn} + (R_t)_{Si} \times \text{Wt\% Si} + (R_t)_{Cr} \times \text{Wt\% Cr}$$

A relationship was obtained (Figure 3) between the cumulative potential, efficiency and volume of oxygen blown per ton of steel. To see how this relationship may be used to find the most efficient oxygen flow rate for a given melt, let us consider a steel whose composition is C 0.4, Mn 0.62, Si 0.45, Cr 0.25, percent just prior to injection. Using

TABLE I

Element Oxidized	R_1	R_2	R_t
Carbon	1.76	4.58	8.07
Manganese	1.00	1.00	1.00
Silicon	1.49	3.92	5.85
Chromium	0.80	1.59	1.27

the previously derived expression for the cumulative potential and the R_t values of Table I, the cumulative potential for this steel is found as follows:

$$\text{C.P.} = 8.07 \times 0.40 + 1.00 \times 0.62 + 5.85 \times 0.45 + 1.27 \times 0.25 = 6.80$$

Figure 3 then shows that the most efficient oxygen injection volume for a melt whose cumulative potential is 6.80 is approximately 180 cu.ft./ton of steel.

The indications of Figure 3 are that as the value of the cumulative potential increases, a greater volume of oxygen per ton of steel can be blown while still maintaining 100 percent efficiency of oxygen usage, and that for a fixed level of cumulative potential, the efficiency falls as the volume of oxygen per ton of steel increases beyond a certain value.

The Possibilities for Deriving Control Charts for Carbon and Manganese Removal

It was considered that by successive integration of the area under such a curve as Figure 1, relationships could be obtained between the amount of element removed and the oxygen blown.

By successive integration of the areas under the curve shown in Figure 1, considerable error is introduced, since the S.O.C. figures used in deriving this curve represent the mean S.O.C. required to remove the number of points of the element lying between the initial and final concentrations, regardless of disturbing influences.

For integration results to be accurate, the S.O.C. figure required when plotting the graph is the value necessary to remove the first 0.01 percent of element below any initial concentration taken. An approximation to this ideal was obtained by searching the data for results which complied with the following conditions:

a. The temperature before blowing oxygen was above 2895 degrees F (mainly 2915 - 2930 degrees F).

b. The results with initial carbon above 0.20 percent and a final carbon above 0.1 percent.

c. The heats of initial carbon below 0.12 percent and a final carbon of not less than 0.05 percent.

d. The manganese concentration was not greater than twice the carbon concentration.

Figure 4 was plotted by using such results, and it can be seen that the major factors causing the scatter shown in Figure 1 are accounted for by full-filling the conditions just mentioned.

On the basis that the indications of Figure 4 represent the most practicable approach to the problem concerning the accuracy of integration, successive

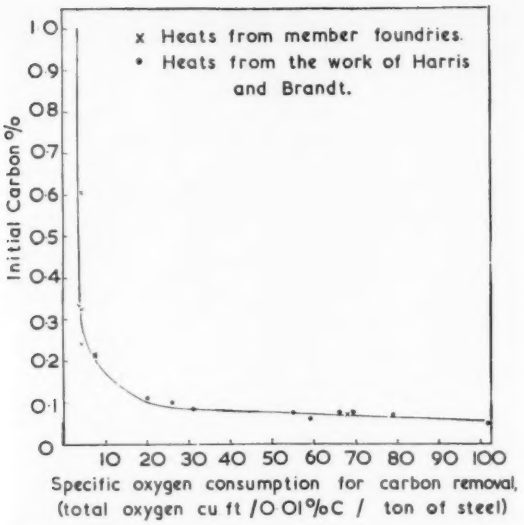

Figure 4—Relationship between specific oxygen consumption and initial carbon content for heats blown at approximately 2910 degrees F and where the following conditions applied:

a. The heats of initial carbon above 0.2% have a final carbon above 0.1%.

b. The heats of initial carbon below 0.12% have a final carbon not less than 0.05%.

c. The temperature before blowing oxygen is above 2895 degrees F (mainly 2910 - 2930 degrees F).

d. The manganese concentration was not greater than twice the carbon concentration.

integration of the area under the curve was carried cut and the results plotted in the form shown in Figure 5, i.e., volume of oxygen required per ton of steel to remove a given number of points of carbon for various initial carbon contents. This control chart is derived from heats blown at temperatures near to 2915 degrees F and so can only be used in that temperature region.

A similar procedure was not possible with manganese since it has not been possible to deduce the quantitative effect of the variables and so reduce the scatter shown in Figure 2. Similarly, with silicon and chromium, the initial concentrations were in most cases so low that no adequate relationship could be or need be drawn.

Conclusions and Suggestions for Future Work

1. The factors affecting the efficiency of carbon removal have been considered and the effect of these is such that:

   a. High initial carbon contents lead to efficient carbon removal.

   b. Low finishing carbon (below 0.1 percent C) reduces the overall efficiency; the lower the finishing carbon, the lower the efficiency.

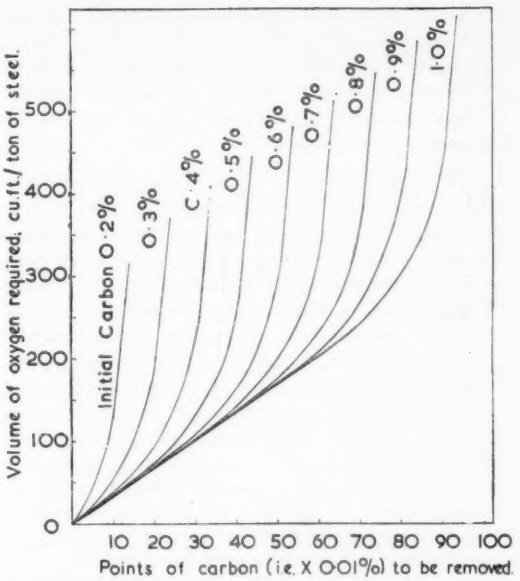

Figure 5—Relationship showing the volume of oxygen required to remove a given number of points of carbon from steels of various initial carbon contents blown at temperatures near to 2910 degrees F.

   c. High temperatures of the metal bath prior to the oxygen injection lead to efficient carbon removal.

   d. High manganese concentrations (of the order of 1 percent Mn) lower the efficiency of carbon removal to some extent.

2. The major factor affecting the removal of manganese is the initial manganese content, and the higher initial manganese concentration, the more efficient is its removal. The factors causing greatest variation in efficiency of manganese removal are the carbon concentration and the temperature. When both these factors are high, low efficiencies of manganese removal result; and when the factors are low, manganese is removed efficiently.

3. An attempt has been made to relate the overall efficiency of oxygen usage to the total metalloid content of the bath. At present there is a lot of scatter in this method of representation. It is possible that as further results are obtained in the BSCRA graphite-rod resistor furnace, with accurate temperature data, a better indication of the overall efficiency at various metalloid concentrations will be obtained by taking into consideration the effect of the various bath temperatures prior to the oxygen injection upon the different oxidation reactions, instead of having to assume a mean temperature for all the heats.

4. The effect of the rate of blowing oxygen requires further consideration. It is intended to obtain results where only the rate of blowing oxygen varies so that an indication of the effect of the rate of oxygen input on the efficiency of oxygen usage can be obtained.

5. The control chart (Figure 5) is derived from heats blown at temperatures near to 2910 degrees F and so can only be used in that temperature region. One of the main aims of future research is to study the effect of temperature on the carbon oxidation reaction, and it is hoped that it will be possible to erect isotherms on curves like in Figure 4. This will be done by obtaining the results of oxygen injection heats with accurate temperature measurement where the final carbon is only a few points below the initial carbon figure. If isotherms can be accurately erected on Figure 4, then control charts like Figure 5 can be obtained for different temperature ranges. If it is found that at lower temperatures the interfering effects of the other elements, mainly manganese, are too great so that the accurate erection of isotherms is not possible, then it is possible that Figure 5 may be used for the calculation of the oxygen requirements to give any desired value of finishing carbon, provided that the volume of oxygen calculated in this way is allowed to correspond with the volume of oxygen which is blown between the appearance of the carbon flame and the end of the blow. Future research work should decide whether this supposition gives good agreement between calculated and actual values of finishing carbon.

References

1. Harris and Brandt. *J. Iron and Steel Institute*, 1950, 165, p. 400.

2. Charles, Chater and Harrison. "Oxygen in Iron and Steel Making" (Butterworth's Scientific Publications), London, 1956.

MEASUREMENT OF STEEL FOUNDRY SAND EXPANSION WITH THE EXPANSION METER

by

Earl E. Woodliff*

A suitable means of measuring thermal growth of steel molding and core sand without the use of dilatometer equipment has recently been developed. This method employs an inexpensive portable instrument with a dry sand core mold designed to allow molten steel to supply activating heat to the standard 2 x 2-inch sand specimen. Testing thermal expansion by casting metal around the specimen has proven to be a simple and reliable test of sand behavior. The results have good reproducibility and present data for quick and reliable interpretation of a sand's quality.

Basicly the instrument is composed of four essential parts: (1) a welded metal frame; (2) a micrometer gauge dial indicator; (3) a core mold assembly, and (4) a core box for making the core (see Figures 1 and 2). The frame provides a base in which a sand bed can be loosely rammed to support the core mold assembly. Two upright arms and a cross member carry the piller block attachment for support and adjustment of the long travel dial indicator. Core molds are made and baked using a regular strong core mixture, such as heavy oil sand.

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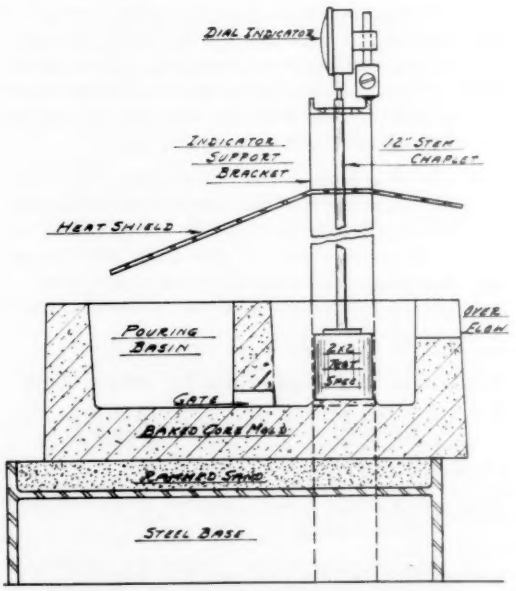

Figure 1—Sketch of expansion meter assembly, section view.

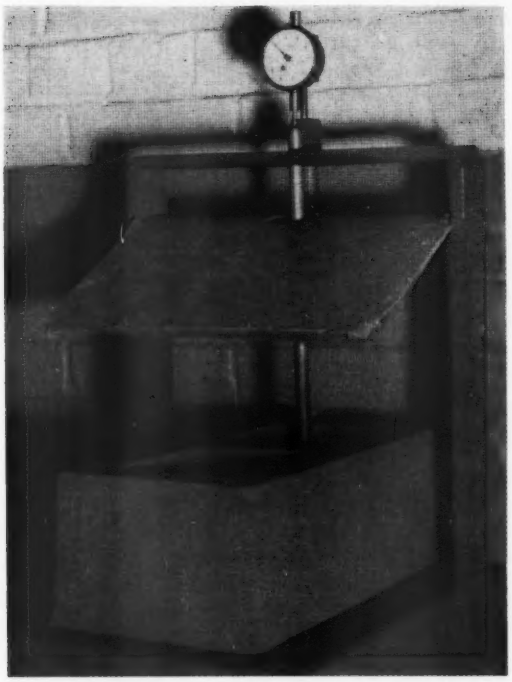

Figure 2—Expansion meter assembly ready for test. Photo by Oil City Works, Corsicana, Texas.

It need not be a special blend but should be strong enough so that rodding of the core will not be necessary. The mixture should contain a minimum of silica flour to keep its expansion low. It has been found desirable to use a core mixture which can be easily duplicated when additional core molds are made. One core mold is consumed in each test; therefore, uniformity of sand mixture and dryness must be maintained to obtain uniformity of results.

The construction of the core mold is much like that of a rectangular pouring basin in which a dam is placed to skim the metal (see Figure 3). The test specimens is attached with core paste to a sand boss or pad which replaces the sprue opening. This is done with a minimum of paste while the specimen is hot from drying or baking. The core mold has an overflow notch in its upper rim to prevent metal from capping over the test specimen when the mold is filled. It allows the mold to fill to within 1/16 inch of the top of the specimen. Two under feed gates through the center dam prevent metal turbulence while pouring and provide an easy metal flow up and around the test specimen.

Readings of sand expansion start as soon as the dial micrometer shows movement from its zero setting. The contact between the test specimen and indicator dial is through a standard twelve-inch stem chaplet machined on its face for full contact, and machined on the stem end for contact with indicator dial contact point. Readings of expansion are taken at one-half minute intervals, from the start through six minutes. If more data are desired, readings may be continued at one-minute intervals.

Interpretation of the data obtained from the expansion meter differs from interpretation of that supplied by the dilatometer, since there is seldom any contraction or shrinkage measured with the expansion meter. Since the expansion of sand has been found to be always a positive growth, three values found most useful in determining the behavior of sand are: (1) expansion per inch of specimen length for one minute; (2) expansion per inch of specimen length for four minutes, and (3) rate of expansion calculated in the following way:

$$\text{Rate of expansion} = \frac{\text{Four-minute expansion} - \text{one-minute expansion}}{3}$$

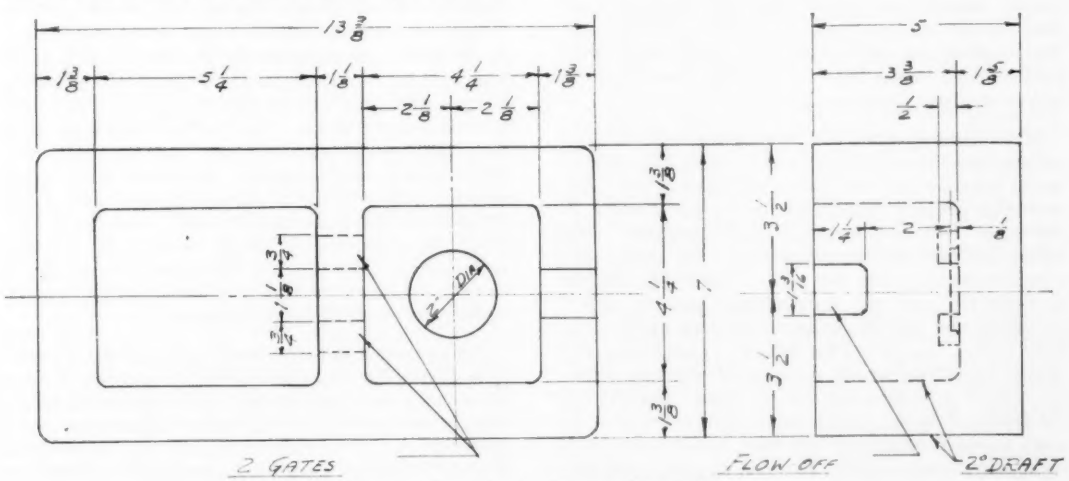

Figure 3—Detail drawing of core mold assembly.

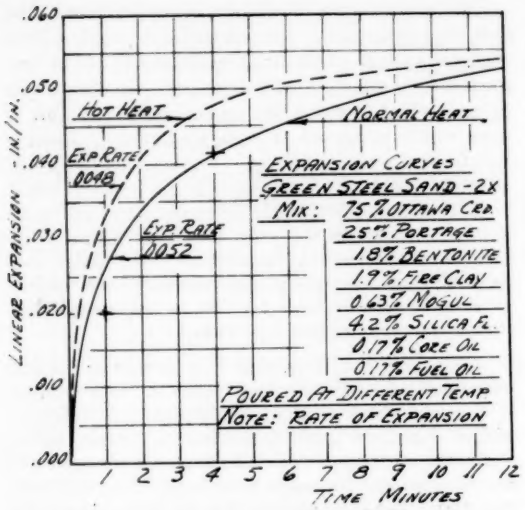

Figure 4—Expansion curves for a steel foundry mixture, poured as green sand, but at different degrees of super heat. No record of pouring temperature given. (Superior Steel & Malleable Castings Co.) 1954.

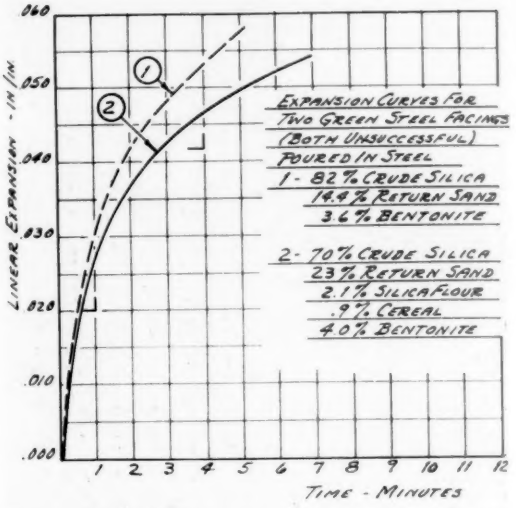

Figure 5—Expansion of two green sand steel facings, showing reduction of expansion by the use of cereal.

The rate of expansion here is the calculated mean expansion for the period between one and four minutes of heating time, or average expansion in inches/inch/minute.

To date, the data for all sands employed for steel molding seem to be close to the values shown below. Suggested safe maximum expansion limits are:

One-minute expansion	0.020 in./in.
Four-minute expansion	0.042 in./in.
Rate of expansion	0.0072 in./in./min.

These are the maximum safe limits found to be applicable; however, by correlation of the test data and casting results, one should attempt to reevaluate them on the basis of sand and binder combinations. These values can only serve as a guide, since conditions which might alter the readings would lead to higher or lower expansion limits.

While investigations have been underway on various steel molding mixtures, a full, comprehensive research program has not been undertaken. Test data show that pouring temperature of the metal is one of the major factors influencing sand expansion. The higher the steel pouring temperature, the greater the expansion readings for any type of sand. This applies to both the one and four-minute control points. However, the rate of expansion remains nearly at a fixed level. Thus it is seen that the expansion of the sand is a function of the pouring temperature, while the rate of expansion is a characteristic property of the sand and binder combination (see Figure 4). It is an accepted fact by many steel foundrymen that high temperature pouring tends to magnify sand expansion defects, such as dirt and casting cracks.

The safest sand mix for use at all pouring temperatures is the one which shows the lowest total expansion and expansion rate. The steel foundryman cannot rely on stabilizers and combustibles, such as sea coal and pitch, for expansion control. However, increasing the content of cereal binders and wood flour tends to retard the expansion and expansion rate of a sand mix as may be seen from Figure 5. The expansion characteristics of baked cores and dry sand molds are of a much lower magnitude, since they contain a larger percentage of organic materials.

The use of silica flour or "fines" in a sand mixture increases the expansion during the initial thermal shock to a mold or core. Hence, its use must either be limited or accompanied by greater use of a stabilizer, such as a cereal binder. Sands of increasing fineness also tend toward higher expansion throughout the heating cycle. Like medium and high silica flour containing mixtures, they, too, must be stabilized to an increasing degree. A broader distribution of sand grain size for molding and core sand mixes has given lower expansion rates than a narrow or uniform grain size. Grain shape seems to be a minor factor, with angular grain sand showing a tendency toward greater expansion and subsequent need for slightly increased stabilizer content.

Molding sand and core sands with higher clay substance have less expansion, but the quantity limitations due to the high strength of the montmorillonite clays limit this from consideration. The writer feels, however, that the increased use of clay would be a practical means of expansion control if less intensive mixing of sand and clay were possible.

RECENT DEVELOPMENTS IN VACUUM DEGASSING OF LIQUID STEEL

Vacuum degassing of liquid steel results in an appreciable upgrading of physical properties because of reduced hydrogen, oxygen, and nitrogen contents. Segregation is minimized, machinability is increased, and impurities at the grain boundaries are virtually eliminated.

Equipment available for vacuum degassing was limited in size and did not lend itself to large scale operations until the advent of the equipment developed by Bochumer-Verein as reported in the April 1955 issue of the Journal of Steel Casting Research.

In this method, a ladle is placed in a vacuum tank, a lid is put in place atop the tank, and the tank is then evacuated. The molten steel is tapped from the furnace into a ladle, which is then moved over the lid of the vacuum tank. The steel is then bottom poured into a pouring basin attached to the lid. The molten steel melts an aluminum sheet disc in the lid of the vacuum tank and falls through a vacuum into the second ladle. The molten metal stream, upon entering the low-pressure area of the vacuum tank, is virtually torn to bits, depending on the degree of vacuum, the diameter of the stream and the rate of pouring. Every effort is made to break up the stream into droplets during the pouring operation in vacuum.

The second ladle is removed from the vacuum tank and the steel is cast in air by conventional methods. The transfer time of pouring for 40 tons of steel is about eight minutes. Replacement of the second ladle by an ingot mold will allow the vacuum casting of ingots up to 150 tons.

Three other methods of vacuum treatment have been developed since the introduction of the Bochumer-Verein system of stream degassing. The Dortmund-Horder Huttenunion has carried on development work on vacuum degassing and has built a pilot plant to test the feasibility of a *continuous*, production scale, process of vacuum treatment as opposed to the Bochumer-Verein batch process. A "vacuum lifter" was designed to be suspended from a mobile platform carried by a crane. The lifter is lowered into the bull ladle, and about four tons of liquid steel are sucked into the vacuum chamber and held until the predetermined gas content is reached. (The 4-ton batch was found to be completely degassified in less than one minute). The degassed metal is returned to the ladle, and the process is then repeated until the entire heat is sufficiently degassed. It was found that about 30 partial treatments were enough to reduce the gas content of an 80-ton basic open hearth heat to a very low level. The total time required for degassing an 80-ton heat was somewhat less than 30 minutes. The oxygen contents of even low carbon steels treated on a large scale were reduced to between 0.003 and 0.006 percent, i.e., one-third of their original values.

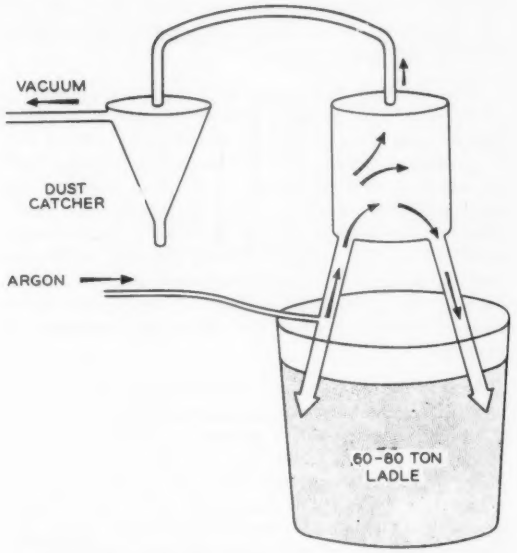

Figure 1—Schematic diagram of the vacuum-flow steel degassing apparatus.

It is well known that the addition of alloying elements and the presence of slag and refractories significantly influence the degassing characteristics of liquid steel. Therefore, deoxidizers and denitrogenizers, as well as alloy elements with a high affinity for oxygen, must be added after completion of the vacuum degassing treatment. The holding ladle must be heated during the vacuum treatment to compensate for the heat losses during this period.

Another recent innovation in vacuum treatment, reported by F. Weston Starratt in the Journal of Metals, July 1958, is the "vacuum-flow steel degassing" method developed at the Heinrichshutte plant of the Ruhr AG. It has been in commercial operation for only six months; and, while operating figures have not been released as yet, the method is apparently successful.

The apparatus consists simply of a small cylindrical vacuum chamber with two pipes extending from the chamber bottom and an outlet pipe at the top. (See Figure 1). The pipes are lowered into a holding ladle and argon gas is blown into the lower end of one of the pipes. A vacuum of 0.1 mm Hg is maintained in the chamber throughout the degassing treatment. This causes the molten metal to flow up one of the pipes into the degassing chamber and down

through the other pipe back into the ladle. A cyclone dust catcher is connected into the exhaust line between the vacuum chamber and the vacuum pumps as shown in Figure 1. Twelve to fifteen minutes are required to degass 60 to 80 tons of metal. Continuous Orsat gas analyses are taken until the gas content drops to the desired value.

This method of vacuum degassing is adaptable to all types of carbon steels as well as most alloy steels. Special care is taken to keep the heats as free of slag as possible, except for certain alloy steels which require a special protective slag. Gas contents are being obtained as low as those of vacuum cast steels. This method has the advantage of low capital investment, since only a small vacuum chamber with connecting pipes and vacuum pumps are required. Thus, vacuum-flow degassing seems to be a promising method of effective, low-cost degassing for large steel castings.

United States Steel has also recently developed a method for vacuum casting large forging ingots. A complete report on this process is given by J. N. Hornak and M. A. Orehoski in the Journal of Metals, July, 1958. The process is designed primarily for the removal of hydrogen to bring the final concentration down to 1.5 ppm. It was found that to reach this level, a vacuum of 0.50 mm Hg was necessary.

Figure 2 shows the principal features of the vacuum tank. The tank is relatively thin walled, because the weight of the transfer ladle is supported by a framework of I beams. Also, because the tank shell is attached only at the base flange and the supporting collar (A and B, respectively, in Figure 2) and because a breather plate has been installed in the tank top, the tank shell is free to move, both vertically and horizontally; so it does not develop excessive localized stresses from severe temperature gradients.

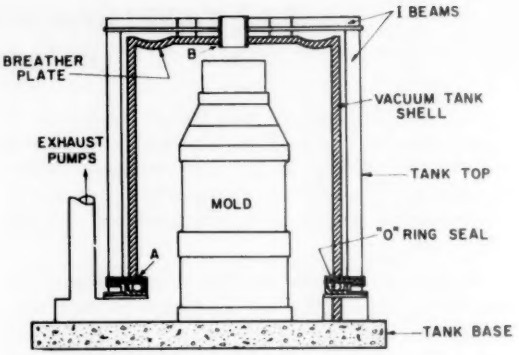

Figure 2—General arrangement of the vacuum tank.

The tank is evacuated, and if the pumping system is functioning properly and the inleakage rate is acceptable, the unit is then ready for the vacuum casting of steel. In the vacuum-casting operation, the steel or tapping ladle is placed over the top of the transfer ladle which is placed atop the vacuum tank. The steel is then poured from the steel ladle into the transfer ladle. When the transfer ladle is about three-quarters full, the nozzle of the transfer ladle is opened, a seal is broken, and the metal is allowed to enter the low-pressure atmosphere within the tank. A special pouring arrangement has been developed which controls the degree of spraying of the steel. The transfer ladle has a 1½-inch diameter nozzle which expands to a 9-inch diameter stream which is then confined by a refractory collar. As a result, the surface of large forging ingots, vacuum cast through an atmosphere of 0.5 mm Hg, is comparable to, or better than, that of air-cast steel. (Bethlehem Steel and Erie Forge and Steel Company are also employing methods of vacuum degassing similar to that used by United States Steel).

RESEARCH PROJECT NO. 19—STUDIES OF DESIGN AS RELATED TO METHODS OF MANUFACTURE

The fatigue and photoelastic studies at Case Institute of Technology, which have encompassed over six years of research, have been completed, and a 20-minute film showing the effects of corner design on stress concentration by means of photoelastic studies has been prepared and released.

The film, "Photoelastic Studies of Joined Sections in Steel Castings and Weldments", has been shown to customer groups, universities and technical societies. It has been well received by them and the reviews and comments have been excellent.

The second revision of the final report on the studies has just been completed by Case Institute of Technology, and results of this study will be distributed to the member foundries as a Research Report sometime this fall.

The static and dynamic (fatigue) experiments were conducted on two geometrically simple structures, which were fabricated as weldments and as castings for the purpose of comparing the performance as a function of the method of manufacture. Different combinations of fillets at the corners were tested in each structure.

THE USE OF STEARIN WAX FOR SIMULATING SHRINKAGE DEFECTS IN STEEL CASTINGS

by

D. B. James and J. M. Middleton

This report describes an investigation sponsored by The British Steel Castings Research Association on the suitability of stearin wax as a material for simulating shrinkage cavities in plain carbon steel castings in the range of 0.2 to 0.3 percent carbon.

The complete report is published in *British Foundryman*, 1958, vol. 51 (1), p. 36-46.

The main part of the work was concerned with producing wax model castings under different conditions and comparing them with carbon steel castings. Several factors, such as cooling rate, superheat, scale effect and wax composition, were studied to determine their effect on shrinkage cavities in stearin wax castings.

Several types of castings were investigated. These included a block shaped casting, 3 x 2½ x 5 inches; L, T and X shapes, bar castings and a gear block casting. Both, pure stearin wax and various alloys of stearin wax with naphthalene, were investigated.

A number of L and X junctions were cast in an 0.25 carbon steel and in stearin wax to learn whether the wax would simulate the solidification characteristics of steel cast into these shapes.

The L junctions were 1½ x 1½ inches in cross section and had an arm length of 5 inches. They were horizontally cast in pairs with the melt being poured through a central head. Two series of stearin L's were cast. One series was poured at 140 degrees F and the other at the freezing point of the wax, i.e., 128.8 degrees F. A comparison of the shrinkage cavities formed in the wax and steel castings is shown in Figure 1.

Similarly, X junctions 1½ x 1½ inches in cross section having an arm length of 5 inches were cast in both steel and stearin wax. The shrinkage defects encountered in these castings are compared in Figure 2. It can be seen that the shrinkage cavities formed in the wax simulated those found in the steel castings. However, the defects in the wax X junctions were slightly larger than those found in the steel castings.

The simulation technique was also applied to a production type casting, i.e., a gear wheel. Five castings were made in both steel and wax using different feeding systems. The wax was poured at a temperature near the freezing point. The wax and steel castings were sectioned and the shrinkage patterns were noted. It was observed that while the wax shrinkage pattern gave a general indication of what could be expected in the steel castings, the shrinkage found in the wax castings was much greater than that observed in the cast steel specimens.

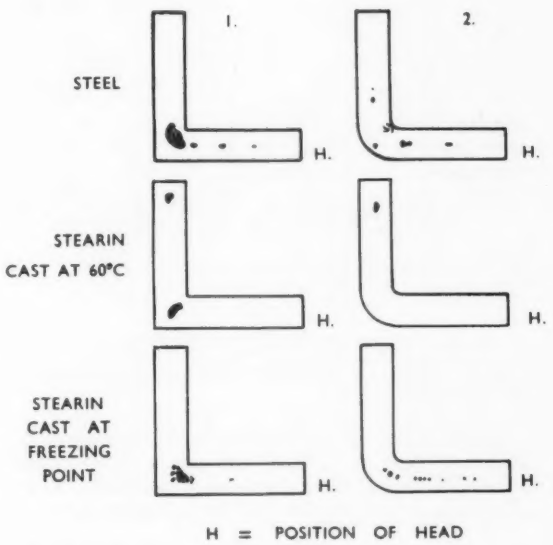

Figure 1—Comparison of shrinkage cavities in steel and stearin wax L-junctions.

The experiments indicated that the best simulations of the shrinkage cavities in steel were obtained in stearin wax which was cast with less than 2 degrees C (3.6 degrees F) superheat. Under these conditions, the extent of shrinkage is greater in wax than in steel. Thus the wax tends to exaggerate any shrinkage cavities present in the steel, and, therefore, a sound casting made in wax would be sound when repeated in steel. However, it was found that a simple application of the wax riser dimensions to steel resulted in gross over-risering which caused poor casting yield. The experiments showed that scaling down the wax models to half size gave approximately the same results, thus riser dimensions must be treated separately from the rest of the casting.

It was shown that end effects are much less in wax than in steel, and that the effects of cores and reentrant angles in delaying solidification are much greater in steel than in wax.

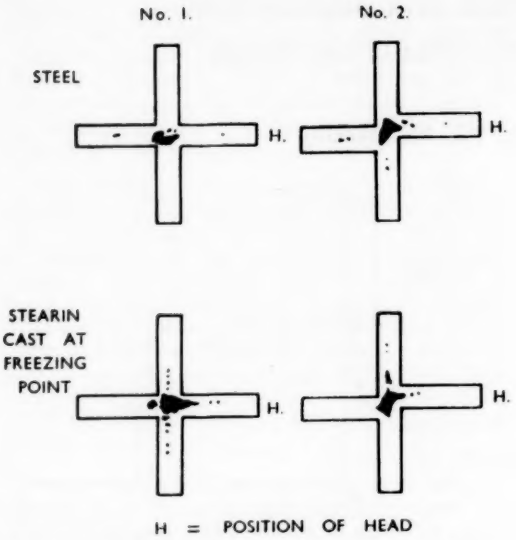

Figure 2—Comparison of shrinkage cavities in steel and stearin wax X-junctions.

The experiments carried out in the investigation indicated that for castings of simple shape good simulation of shrinkage defects was obtained, and if allowances were made for shrinkage defects, the wax technique could be of assistance in solving feeding problems. However, the simulation effect became less effective with more complicated castings, because of such factors as core effect, end effects, re-entrant angles, and number of risers needed.

It was also observed that:

1. It was practically impossible to ensure a superheat of 3.6 degrees F with melts greater than 1 gallon.
2. Addition of naphthalene to stearin wax did not give any better simulation than pure stearin wax near its freezing point.
3. The L and X junction castings showed that stearin wax reproduced the shrinkage patterns observed in steel. However, the shrinkage was more severe in wax castings than steel castings.
4. An atmospheric riser was not nearly as effective in wax as in steel.
5. The maximum length of bar (2 x 2 inches in cross section) which could be fed to soundness in wax was only half that for steel.

It can be concluded from these studies that qualitatively the stearin wax/steel analogy holds true and can be used to detect the regions in a casting which are liable to contain shrinkage. The analogy cannot be utilized to solve feeding problems in the case of castings other than simple shapes.

THE USE OF SODIUM-SILICATE MOLDING MIXES WITHOUT CARBON DIOXIDE HARDENING

An article appearing in the German publication Giessereitechnik, Vol. 3, 1957, by A. Gebauer and O. Gerstmann presented some interesting information on the use of sodium silicate bonded sands for molds. The information was obtained through a study conducted at the Leipzig Electric Steel Foundry using both gray iron and steel castings. The authors discuss the advantages of air hardening sodium silicate molding mixes in preference to curing with CO_2. The article is summarized below.

Advantages of Sodium-Silicate Molding

The authors indicate that a pattern can easily be drawn from molds made of sodium-silicate sands that have not been cured with carbon dioxide. The danger of tearing off edges and corners and the pattern draft requirements are greatly reduced over the use of CO_2 hardened sands. The high strengths produced by CO_2 curing are often required for cores but are not necessary for molds. However, a minimum green strength is essential if the pattern is to be removed before the sand is cured. For these reasons, a sand mix bonded with clay and sodium silicate is used to produce molds that are air cured after the pattern is drawn.

Sodium Silicate

The sodium silicates used are similar to those used to produce CO_2 cores. The specific gravity should be 1.5, or in a Baumé range of 48-50°, with a Na_2O/SiO_2 mole ratio of about 1:2.5. Such a sodium silicate contains about 45 percent solids and 55 percent water by weight. The use of lower specific gravity material, e.g., 36° Baumé, is not recommended as the amount of steam generated during pouring is much greater.

Sand

The moisture content of the sand is quite important and should be in the range of 0.3 to 0.6 percent. Completely dry sands should be tempered to this moisture content prior to adding sodium

silicate, since the resistance of the sodium silicate molding sands to abrasion is reduced when completely dry sands are used.

The grain size of the sand is also quite important, and most of the sand grains should fall between 0.008 to 0.012 inches, i.e., the majority of the sand should not pass through the No. 70 screen. The fine material (through the No. 270 screen) must not exceed 1 percent. The facing sand may be made of all new sand or a mixture of new and old in the ratio of 2:1, provided the limitation on fines is observed.

Mulling

The mulling cycle is quite critical and time limitations should not be exceeded. The authors did not indicate the type of mulling equipment used, but the time cycles recommended were as follows:

The time of mulling should be kept as short as possible to prevent drying in the muller. The dry components should be well mulled for 1-2 minutes, and after the addition of sodium silicate the mulling is continued for 2-3 minutes. Extending the mulling cycles beyond 5 minutes impairs the quality of the molding mix. If satisfactory mixing cannot be attained in 5 minutes, then mulling must be improved by adjusting the blades, scrapers and plows of the muller.

After it is discharged from the muller, the sand should be placed into containers that are reasonably air tight to prevent hardening. The sand mix should not be allowed to stand long before it is used. Only enough sand for a day's work should be made.

Molding and Curing

Two types of sands are used: a sodium silicate facing sand and a backing sand. The facing sand is spread over the pattern to a depth of 1¼ to 2¼ inches, depending upon the type of casting being produced, and the flask is filled with backing sand.

The molds faced with sodium silicate sand can be hardened by drying in air, or in ovens. The strength attained is usually higher than that attained by carbon dioxide hardening. The plasticity of the molding sand is raised, and the curing time is improved if materials such as fire clay or bentonite are added. The hardening time for large molds can be appreciably reduced by skin drying the molds with a gas flame.

Figure 1 shows the increase in compressive strength of 2-inch specimens made of various sodium-silicate bonded sands as the air drying time is increased. The mixtures shown contain bituminous coal dust because they were for gray iron castings. However, the data are significant in showing the effect of increasing amounts of sodium silicate. The strengths of these sand mixes decrease fairly regularly with increasing coal dust contents. The only variable was

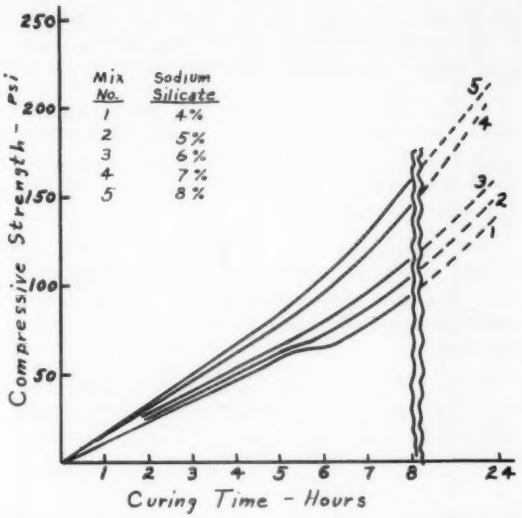

Figure 1—Effect of curing time on the compressive strength of various sodium silicate bonded sand mixes.

sodium silicate and the base composition was as follows:

Silica sand	90 - 86 percent
Bituminous coal dust	4.0 percent
Clay	2.0 percent
Sodium silicate (48-50 Bé)	4-8 percent

The sand mixes containing either 5 or 6 percent sodium silicate provided sufficient strength, and it was usually unnecessary to increase the amount to 7 or 8 percent. The larger amounts of sodium silicate increase the shakeout problems as the degree of mold hardening is increased.

Air hardening of these molding sands is benefited by the use of a fairly open sand as the more compact sands (permeability less than 80) dry more slowly. Sands containing excess amounts of fines require more binder if the same strength level is to be attained.

The following two molding sand mixes were reported as giving good steel casting results:

	Parts in weight per cent Mix 1	Mix 2
Silica Sand	60	59
Reclaimed Sand	30	30
Bentonite (Hungarian)	3	4‡
Sodium Silicate 48-50 Bé	7	7

‡ percent clay (Friedland blue)

The bentonite mixture is recommended for castings prone to scabbing or subjected to strong erosive action. The above mixes may be varied within narrow limits. Sodium silicate contents of 5 to 6 per-

cent were successfully used in some cases. However, it is inadvisable to depart greatly from the composition listed above.

Mold washes were not used, but the casting surfaces were improved when the mold was powdered with graphite as soon as the pattern was drawn. The molds were allowed at least 3 hours to air harden; 5-6 hours were preferred.

The authors feel that air hardening (drying) of sodium silicate sands is best suited for molding sands and the carbon dioxide hardening of sodium silicate sands is best suited for cores or for stack and battery molding.

Sodium silicate molding sand can be reclaimed for reuse, but the sand should be immediately reclaimed while it is still hot "steaming", as under these conditions the molding sand disintegrates readily.

Summary

1. Sodium silicate-clay bonded sand mixes have sufficient green strength to permit pattern withdrawal without previous carbon dioxide hardening.
2. Sodium silicate-clay bonded molding sands can be hardened by air drying in 3 to 6 hours. The hardening time can be shortened by skin drying or placing molds in drying oven. The sodium silicate content should be as low as is feasible to produce quality castings.
3. The mulling cycle is critical and should be limited to five minutes.
4. Low viscosity sodium silicate (36 Bé) should be avoided because of excessive amounts of steam released while the casting is solidifying.
5. A sodium silicate with a viscosity in the range of 48-50 Bé is recommended.
6. Coarse sands should be used to permit air drying as well as to permit the use of a lower percentage of sodium silicate. Ninety percent of the sand grains should be retained in the 40, 50 and 70 screens.
7. One-third reclaimed sands may be used if the fines are less than 1 percent.

PHOTOMETRIC METHOD OF DETERMINING THE CLAY CONTENT OF FOUNDRY SAND

The development of a method to determine the amount of active or usable clay in used foundry sand could result in a marked improvement in sand control and reduced costs in the steel foundry industry. An article published in the Report of The Castings Research Laboratory, No. 8, 1957, Waseda University, Tokyo, Japan, entitled "Testing Method of Clay Content in Foundry Sand" and written by Dr. Jiro Kashima, contains some very interesting information on a possible solution of this problem. Although the report is not conclusive and several aspects are quite vague, a method of clay determination is suggested which may well prove to be of value.

The determination of the fire clay content of foundry sand by measuring the clay's ability to adsorb organic coloring matter has been applied for many years, and a considerable amount of information on this method has been published. Recent developments in analytical photometry have also increased the reliability and accuracy of such adsorption tests tremendously. However, this method has never been successfully applied to bentonites because of instability of the organic compounds used as coloring agents.

The purpose of this investigation, therefore, was to find a more stable coloring agent which could be used to apply the improved photometric techniques to the determination of bentonite contents of foundry sands. The most promising coloring agents appeared to be those having positive ions, which do not change valence when dissolved and are easily analyzed photometrically. Copper and nickel satisfy both of these conditions.

Adsorption Test With Cu^{++}

The copper ion is stable in neutral or acidic solutions and can be analyzed photometrically with ease as an ammoniacal solution of cupric sulphate (complex salt solution). Preliminary tests were run with 1-gram samples of bentonite and fire clay. Two samples of each clay were used, one being heated to 212 degrees F and the other to 1470 degrees F before testing to simulate heat conditions encountered in a mold.

Copper sulphate was dissolved in water to a concentration of 25 mg/100cc. This concentration was used to simplify photometric analysis. One-gram

samples of clay were added to 50cc of this solution, and the mixture was stirred for an hour in a thermostat bath at a temperature of 30 degrees C, ± 1 degree C. The mixture was then placed in a centrifuge and the clay separated at 3,000 rpm. One cc of ammonium solution (conc.) was added to 25cc of clarified solution and the volume adjusted to 100cc. The copper adsorbed by the clay was then determined on the photometer using a 6100A° filter. The adsorption abilities of the samples are tabulated in Table I.

It is obvious that there is a relationship between the ability of the clay to adsorb copper ions and the degree of burning of the clay. Similar tests were conducted on silica sand to ascertain the influence of the sand in the adsorption determination. The variation of adsorption characteristics of the sand with respect to previous heat exposure was found to be negligible.

One of the objectives of the study was to establish a means of determining the adsorption characteristics of foundry sand when fire clay and bentonite are used jointly as binders. Since the adsorption phenomenon is believed to depend upon the ion exchange between hydrogen ions and metallic ions, and the pH of bentonite and fire clay is different, an attempt was made to nullify the pH variable. Small amounts of sulphuric acid were added to the sulphuric copper solution, and the adsorption tests were repeated. Results showed that the ability of both clays to adsorb copper ions was reduced as the acidity was increased. However, when the free sulphuric acid exceeded a concentration of N/10, the adsorption characteristics were found to be independent of the concentration of the acid.

Difficulty was encountered, however, in the testing of sand-clay mixtures with the copper solution. The use of a sand-clay mixture reduced the amount of clay available in a given size sample so drastically that the photometric analysis for copper was not able to detect the slight variations in adsorption ability. The use of a more sensitive indicating reagent to detect these slight variations resulted in a solution which was beyond the color range of photometric analysis. For this reason tests were performed with a nickel ion solution.

TABLE I—

Copper Ion Adsorption Characteristics of Bentonite and Fire Clay After Exposure at 212 and 1470 degrees F.

Material	Exposure Temperature °F	Adsorption mg/g of Clay
Bentonite	212	19.00
	1470	4.00
Fire Clay	212	3.37
	1470	1.24

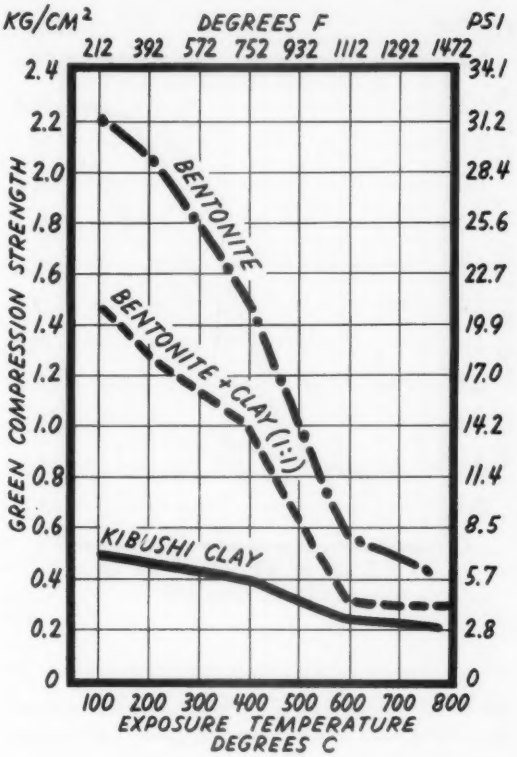

Figure 1

Adsorption Tests With Ni++

In the photometric analysis by Ni++, 1 gram of clay is added to a nickel sulfate solution (Ni++ 4.18mg/100cc) as in the analysis by Cu++. Bromine water and dimethyl glyoxime are added to 25cc of the clarified solution, and the determination is carried out using a 4300A° filter.

The limiting concentration of acid affecting adsorption was again found to be N/10. The Ni++ analysis is sensitive and has a wide range of application. The results of preliminary tests showed a definite relationship between the ability to absorb Ni++ and the temperature of previous heat exposure for bentonite, fire clay, and a 1:1 combination of the two.

Relation Between Adsorption and Green Compression Strength

Green compression sand samples were made of 10 parts of sand, 1 part binder and 1 part water. Bentonite, fire clay and a 1:1 combination of bentonite and fire clay were used as binders. The binders were exposed to heat at various temperatures before

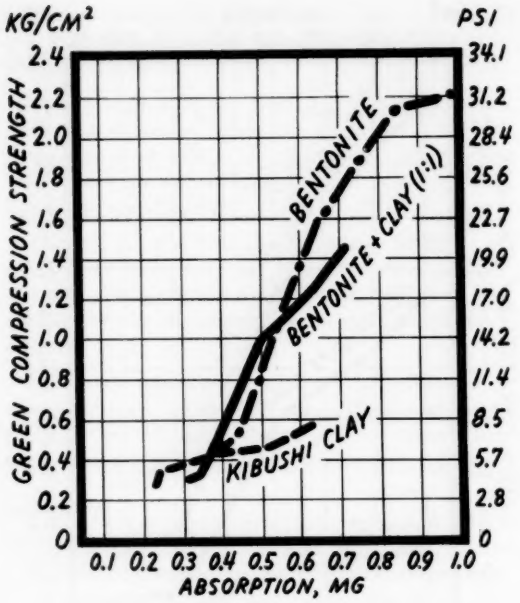

Figure 2

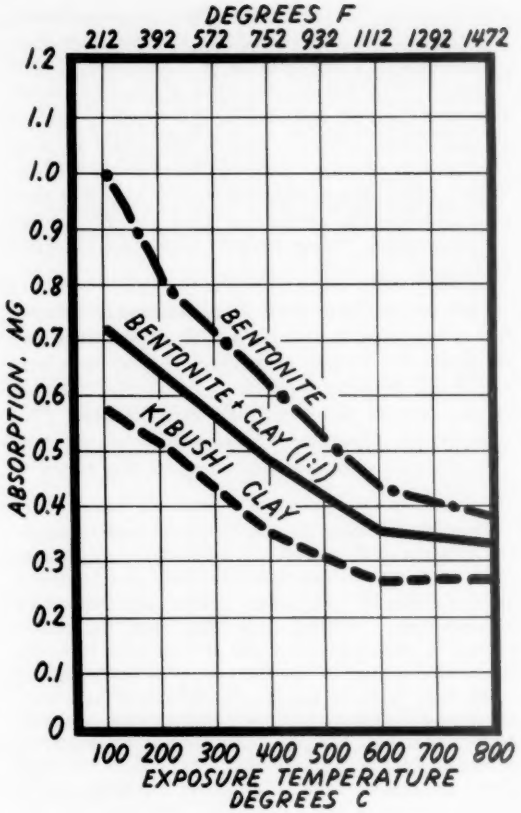

Figure 3

the samples were prepared. The relationship between the temperature of exposure and green compression strength is shown in Figure 1, and between adsorption and green compression strength in Figure 2. Figure 3 shows the variation of adsorption with exposure temperature.

Thus it can be seen that there is a relationship between the amount of active clay in the sand and the ability of the sand and clay mix to absorb Ni^{++} ions and that it is possible to measure the variations in adsorption ability photometrically. A more accurate correlation of these properties might very well prove to be an answer to the problem of determining the amount of usable clay remaining in used foundry sands.

SFSA-BSCRA EXCHANGE LECTURE

The Board of Directors, at its meeting on April 16, 1958, appointed Mr. C. W. Briggs, Technical and Research Director, SFSA, as the Society's representative to the British Steel Castings Research Association's Annual Conference to be held in Harrogate, England, October 23 - 24, 1958. The theme of this year's program will be "Steelmaking and The Properties of Steel Castings", Mr. Briggs will present the Second Exchange Lecture between Steel Founders' Society and the British Steel Castings Research Association on "The Deoxidation and Degassing of Cast Steels". This series of exchange lectures between the two organizations began in 1957 when Messrs. T. A. Cosh and L. W. Sanders presented the first lecture at the 12th Annual Technical and Operating Conference.